Terra MODIS On-Orbit Spatial Characterization and Performance

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***Abstract*—The Moderate Resolution Imaging Spectroradiometer (MODIS) Proto-Flight Model, onboard the National Aeronautics and Space Administration's Earth Observing System Terra spacecraft, has been in operation for over four years. It has 36 spectral bands and a total of 490 detectors located on four focal plane assemblies (FPAs). MODIS makes observations at three spatial resolutions (nadir): 0.25 km (bands 1–2), 0.5 km (bands 3–7), and 1 km (bands 8–36). The instrument's spatial characterization was measured prelaunch using an integration and alignment collimator. Parameters measured included the detectors' instantaneous field-of-view (IFOV), band-to-band registration (BBR), and line spread function in both the along-scan and along-track directions. On-orbit, the spatial characterization is periodically measured using the onboard spectro-radiometric calibration assembly (SRCA). This paper describes the SRCA BBR algorithms, characterization methodologies, and on-orbit results. A Fourier approach used to calculate the along-track BBR is also described. This approach enhances the algorithm's robustness in comparison with the conventional centroid approach. On-orbit results show that the Terra MODIS focal planes shifted slightly during launch and initial on-orbit operation. Since then they have been very stable. The BBR is within 0.16 km (nadir IFOV) in the along-scan direction and 0.23 km (nadir IFOV) in the along-track direction among all bands. The small but noticeable periodic variation of the on-orbit BBR can be attributed to the annual cycling of instrument temperature due to sun–earth distance variation. The visible FPA position has the largest temperature dependence among all FPAs, 17 m/K along-scan and 0.6 m/K along-track.**

***Index Terms*—Calibration, instrument, remote sensing, spatial alignment.**

I. Introduction

The Moderate Resolution Imaging Spectroradiometer (MODIS) Proto-Flight Model (PFM) has been operating on-orbit since its launch on December 18, 1999, providing continuous global data for studies of the earth's land, oceans, and atmosphere [1]–[3]. It has 36 spectral bands located on four focal plane assemblies (FPAs) covering wavelengths in the visible (VIS), near infrared (NIR), short- and midwave infrared (SMIR), and longwave infrared (LWIR). The SMIR and LWIR FPAs are radiatively cooled to their nominal operating temperature of 83 K. MODIS has three different nadir ground spatial resolutions: 0.25 km (bands 1–2), 0.5 km (bands 3–7), and 1 km (bands 8–36). For bands with subkilometer resolution, multiple subsamples are acquired in the along-scan direction (four for bands 1–2 and two for bands 3–7). In the along-track direction, there are 40 detectors per band for bands 1–2, 20 detectors per band for bands 3–7, and ten detectors per band for bands 8–36. MODIS bands 1–19 and 26 with wavelengths from 0.41–2.2 μm are categorized as the reflective solar bands (RSBs), and the remaining are the thermal emissive bands (TEBs) with wavelengths from 3.5–14.5 μm.

Manuscript received May 10, 2004; revised October 13, 2004.

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Digital Object Identifier 10.1109/TGRS.2004.840643

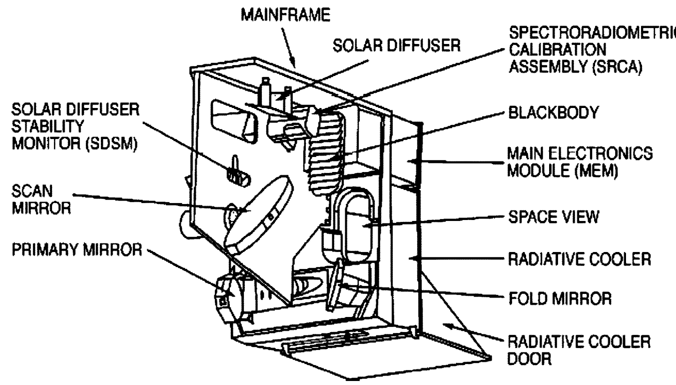

Fig. 1. MODIS instrument.

As shown in Fig. 1, MODIS uses a double-sided scan mirror that views the onboard calibrators (OBCs) and the earth scene at 20.3 r/min. It is equipped with a number of onboard calibrators: a v-grooved blackbody (BB), a solar diffuser (SD), a solar diffuser stability monitor (SDSM), a spectro-radiometric calibration assembly (SRCA), and a spaceview port (SV). They are located opposite the earth view. Hence, when the scan mirror is rotating, one side of the mirror views the earth scene, and the other side consecutively views the calibrators. The BB and SV data used for calibration of the thermal emissive bands are obtained every scan, while the SD and SDSM were operated weekly during the first year and biweekly thereafter for calibration of the reflective solar bands [4]–[6]. The SDSM is used to track SD reflectance degradation on-orbit.

The SRCA has three operational modes: spatial, spectral, and radiometric. The spatial mode, operated bimonthly, is used to track the band-to-band registration (BBR) of all 36 bands from prelaunch to on-orbit and their changes over time [7]–[9]. In spectral mode, operated trimonthly, the SRCA functions as a self-calibrated monochromator to characterize RSB spectral response and center wavelength shifts [10], [11]. The radiometric mode, typically operated monthly, is used to monitor RSB response changes at an angle of incidence (AOI) of 38.2° to the scan mirror and to support the RSB calibration by the SD (i.e., performed at an AOI to the scan mirror of 50.2°) [12].

The SRCA contains VIS/NIR and infrared (IR) sources, a monochromator or optical relay, and a collimator (Fig. 2). The VIS/NIR source is a spherical integration source (SIS) with four 10-W lamps and two 1-W lamps (one of the 10-W lamps and one of the 1-W lamps are backups) to provide multiple levels of illumination for the RSB characterization. A thermal source provides IR energy. When the SRCA is in spatial mode, a beam-combiner on the filter wheel is used. The light coming out of

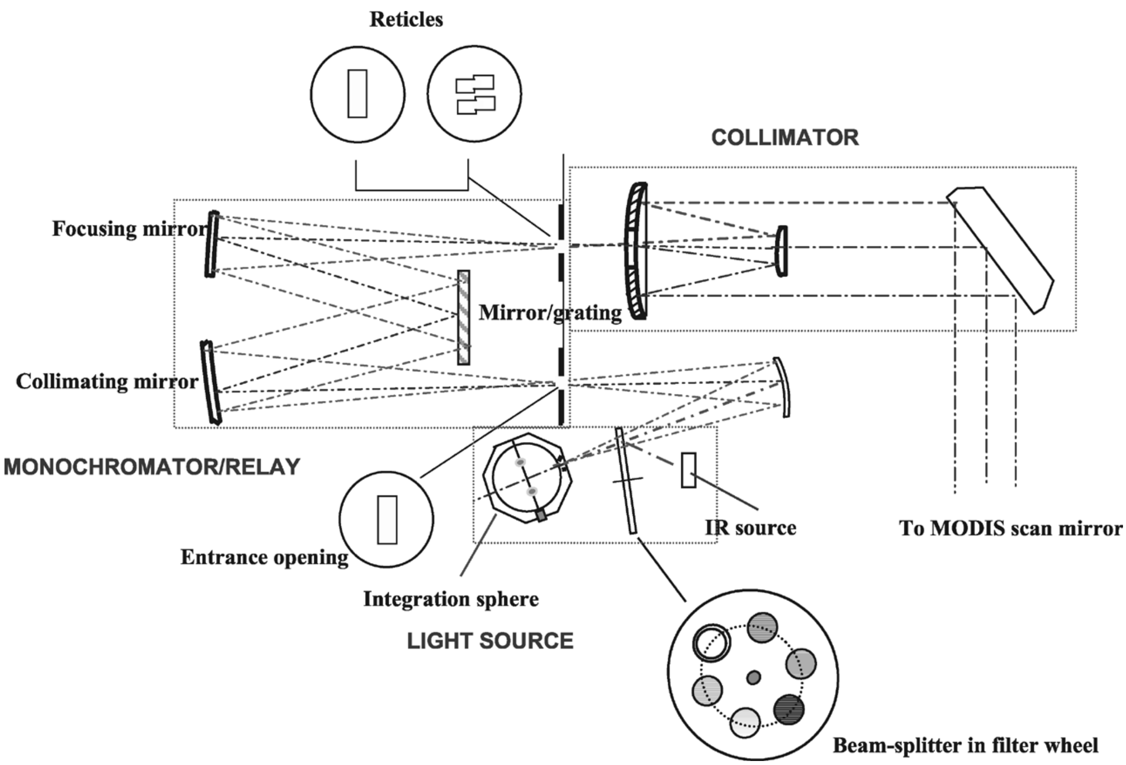

Fig. 2. Layout of the SRCA.

the SIS passes through it while the IR beam is reflected from its surface. The combined beams provide illumination for all 36 bands. The light passes through the beam combiner and is focused onto the monochromator's entrance slit. After reflection by a collimating mirror, the beam passes onto a mirror or grating (the grating is used for the spectral characterizations). The beam is then refocused onto an exit slit (or various interchangeable reticles) by the focusing mirror. The follow-up Cassegrain telescope system expands and collimates the beam before it exits the SRCA and is viewed by the MODIS scan mirror.

When the SRCA is in spatial mode, an entrance slit equivalent to a 5 km (scan direction) $\times$12 km (track direction) nadir IFOV [Fig. 3(a)] is used. The mirror, instead of the grating, is in position so that the monochromator functions as a simple optical relay system. Located at the exit position are two reticles: one for along-scan, which is identical to the entrance slit [Fig. 3(a)], and the other for along-track [Fig. 3(b)] with stepped openings. The two reticles are positioned in turn to measure MODIS spatial response in both directions. The SRCA collimator and the MODIS optics image the reticles onto the FPAs.

In the spatial mode, the IR source is on, and the lamps inside the SIS are turned on in sequence of three 10 W, two 10 W, one 10 W, and 1 W. Each band utilizes one light-source configuration for its optimal (i.e., on-scale) signal. Since the lamps need warm-up time, both the along-scan and along-track measurements are performed at each lamp configuration before it is changed.

VI. Conclusion

The SRCA measures the band-to-band registration changes from prelaunch to on-orbit so that the on-orbit BBR can be tracked after correcting for the bias between the IAC and the SRCA. The BBR algorithms for along-scan and along-track measurements have been presented. The Fourier approach for the along-track BBR calculation improves the measurements' robustness. The prelaunch tests show that the Terra MODIS BBR meets the specification with only a few exceptions along-scan. The BBR has changed very slightly on-orbit. Four years after launch, the BBR is still in specification (0.2 km) along-scan, but 30 m larger than the specification along-track (band 26 to band 30 only). The BBR varies with instrument temperature. The VIS FPA has the largest temperature coefficients. The along-scan FPA averaged temperature coefficients are 16.7 ± 3.2 m/K (VIS), 0.0 ± 0.3 m/K (NIR), 3.6 ± 1.0 m/K (SMIR), and 4.0 ± 1.6 m/K (LWIR). The along-track coefficients are -0.6 ± 0.6 m/K (VIS), 0.0 ± 0.1 m/K (NIR), 1.0 ± 1.2 m/K (SMIR), and -2.8 ± 0.9 m/K (LWIR).

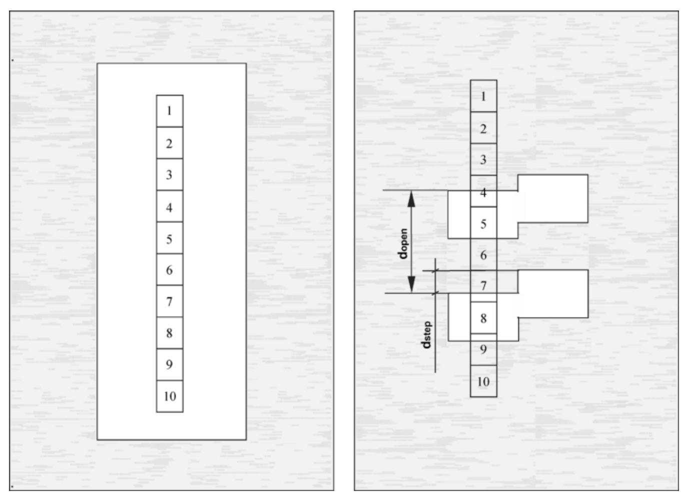

Fig. 3. SRCA spatial mode reticles (a) along-scan and (b) along-track.